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UNITED STATES PATENT AND TRADEMARK OFFICE

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For and on behalf of RWS Group Ltd

The 16th day of October 2006

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**Priority Certificate
for the filing of a Patent Application**

File Reference: 101 33 842.2

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Applicant/Proprietor: Carl Zeiss, 89518 Heidenheim/DE

Title: Retardation plate made from cubic crystal

IPC: G 02 B, G 03 F

The attached documents are a correct and accurate reproduction of the original submission for this Application.

Munich, 26 April 2004

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Agurks

Description:

01087P

Retardation plate made from cubic crystal

[0001] The invention relates to a retardation plate
5 made from cubic crystal. Such a retardation plate is
disclosed, for example, in the applicant's
US 6,191,880 B, where a retardation plate, that is to
say a birefringent plate that effects a phase shift
10 between two mutually orthogonally polarized penetrating
beams, and can be designed, for example, as a $\lambda/4$ plate
or $\lambda/2$ plate, is described as a plate which made from
calcium fluoride, which exhibits strain birefringence
owing to external forces or to the production process.
Nothing is stated there regarding crystal orientation.

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[0002] Because of their symmetry, cubic crystals do
not normally exhibit birefringence.

[0003] Residual strain birefringence induced by the
20 production of optical elements made from calcium
fluoride is disclosed in US 6,201,634 B1.

[0004] Classical birefringent crystals such as
magnesium fluoride exhibit birefringence at such a high
25 level that only very thin plates are required, but
these throw up technical problems, as may be gathered,
for example, from DE 197 04 936 A (US ser.
No. 09/017,159) and the applicant's US 6,084,708 B.
Although inherently possible and customary thicker
30 retardation plates with a path difference $(n+1/4)$
 λ -retardation plates of n th order - are thicker, they
require the same narrow thickness tolerance and have a
much lower angular tolerance for light.

[0005] Many other known materials for retardation plates are not available in the ultraviolet region from 200 to 150 nm and below, because of excessively high absorption.

5

[0006] It is known from the Internet publication "Preliminary Determination of an Intrinsic Birefringence in CaF_2 " by John H. Burnett, Eric L. Shirley and Zachary H. Levine, NIST Gaithersburg MD 20899 USA (posted on 07.05.01) that calcium fluoride single crystals also exhibit birefringence that is not induced by strain and is therefore intrinsic. The measurements presented there show that a birefringence of (6.5 ± 0.4) nm/cm occurs at a wavelength of $\lambda = 156.1$ nm in the case of beam propagation in the direction of the $\langle 110 \rangle$ crystal axis. Measurements by the applicant indicated 11 nm/cm. By contrast, birefringence is low in the other crystal axis directions.

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[0007] It is an object of the invention to specify an alternative design of retardation plates that is suitable for wavelengths in the region of 200 to 150 nm and below, and permits very exact functioning in conjunction with a moderate outlay on production.

[0008] High-quality retardation plates for this wavelength region are required in microlithography projection exposure machines, in particular in conjunction with catadioptric projection objectives. They are urgently required for projection objectives with polarization beam splitters as quarter-wave retardation plates between beam splitter and concave mirror. In the case of other types having deflecting mirrors with a deflection of approximately 90° , the reflection near the Brewster angle leads to polarization-dependent reflectivities that must be compensated.

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[0009] This object is achieved by means of a retardation plate as claimed in claim 1.

5 [0010] Thus, the residual birefringence of calcium fluoride, which has a maximum for beam penetration parallel to the $\langle 110 \rangle$ crystal axis, or parallel to a main axis of the crystal equivalent thereto, and which has hitherto been regarded as a problem of lens systems made
10 from this material, is used in a targeted fashion as operating mechanism for the retardation plate. Because of the relatively low birefringence, the plate is several centimeters thick, but even for very accurate retardations its thickness is important only in a range
15 that is not problematic for the production of optical elements.

[0011] Apart from this intrinsic birefringence, a relatively high value is also attached to strain
20 birefringence caused by production conditions in the direction claimed in accordance with US 6,201,634 B. The thickness of such a retardation plate with a desired retardation, for example as a quarter-wave retarder, can be determined from the measured value of
25 the birefringence of the concrete material charge, and both causes of birefringence can thereby be taken into account.

[0012] In addition, the inventors have established
30 that barium fluoride single crystal likewise exhibits such birefringence, although with about twice the value of 25 nm/cm. Consequently, barium fluoride with the same orientation is also suitable, but has the advantage of about half the thickness.

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[0013] It is clear that all other crystals are also suitable in the same way if they exhibit a similar birefringence. However, these values are not presently

known for the other fluoride crystals that are transparent in the deep ultraviolet. A specification with reference to the strain birefringence induced by production is known only in US 6,201,634 B for
5 strontium fluoride.

[0014] By comparison with extremely thin MgF_2 retardation plates, the use of CaF_2 or BaF_2 has the advantage that the thicknesses are in the cm range.
10 This greatly simplifies the reduction of the retardation plates.

[0015] Further embodiments are the subject matter of the subclaims.
15

[0016] The half-wave plates and the quarter-wave plates are important designs of the retardation plates, the design according to the invention consisting of materials of relatively weak birefringence being
20 particularly suitable for producing plates of zeroth order. With the latter, the path difference is equal to $(0+1/4)\lambda$ or $(0+1/2)\lambda$, and so a non-effective path difference of a multiple of the wavelength is not introduced in addition. This is unavoidable for plates
25 made from magnesium fluoride in order to achieve plate thicknesses that can be handled, but it does effect a limitation of the angular acceptance.

[0017] Particularly advantageous is the design provided
30 as claimed in claim 5, wherein the retardation plate bears a functional face. It is possible without effectively influencing the retardation or the polarization rotation to provide one or both end faces with a structure that acts refractively or diffractively.
35 Fresnel lenses, zone plates, refractive or diffractive grid plates and the like with pattern heights up to the millimeter range can therefore be provided without an additional component. Such a component can be used, for

example, in the illumination system of a microlithography projection exposure machine to simultaneously influence the polarization distribution and to increase the photoconductance. It is also possible for one or both
5 end faces to be curved spherically or aspherically or as a free-form surface, such that the retardation plate can simultaneously contribute to the correction of an optical system. It is thus also possible for a substantially curved meniscus to serve as retardation
10 plate according to the invention when the light path corresponds sufficiently accurately only to the desired retardation over the entire cross section.

[0018] The stress-free bearing as claimed in claim 6
15 means that the retardation plate can be supported using normal mounts, such as are also used for lenses, filter plates and the like. Expensive apparatuses for homogeneous introduction of force in accordance with US 6,084,708 B for example, are eliminated just as are
20 problems in the holding of particularly thin elements.

[0019] The preferred use in microlithography is described in claims 7 to 10.

25 [0020] The invention will be explained in more detail with the aid of exemplary embodiments by comparison with designs made from magnesium fluoride.

[0021] A quarter-wave plate of zeroth order for
30 wavelength 157 nm has a thickness of 39 mm when made from calcium fluoride of retardation 10 nm/cm, and a thickness of 15.7 mm when made from barium fluoride with a retardation of 25 nm/cm. In the case of deviations in the retardation with material charge -
35 for example owing to strain birefringence caused by production - the required thickness changes in proportion to the deviation in the retardation. Plates of such thickness can be produced with the typical

dimensions of lenses, currently up to approximately 300 mm in microlithography optics. They can be mounted or supported using the existing technology for lenses.

5 [0022] A corresponding quarter-wave plate of zeroth order for 157 nm made from magnesium fluoride has a thickness of only 5.5 μm (compare US 6,084,708 B). The problem of stable support can be solved by wringing to a thicker element such as, for example, a beam splitter
10 prism. However, it remains a problem to produce such a thin crystal plate with diameters of over 100 mm (compare DE 197 04 936 A). A quarter-wave plate of twentieth order also has a thickness of only approximately 0.22 mm. The deviation from the accurate
15 quarter-wave retardation owing to thickness variation has precisely the same relationship in the case of plates of zeroth or higher order. Consequently, with magnesium fluoride a thickness deviation of only 0.5 μm is attended by a phase deviation of approximately 20%
20 that cannot be used.

[0023] In the case of the inventive retardation plate of zeroth order made from calcium fluoride, a phase error of 2% likewise corresponds to a thickness error
25 of likewise 2%. However, this 2% is 0.8 mm owing to the thickness of 39 mm. The normal production of optical elements is much more precise, and so the thickness constitutes no problem at all in production. The same holds for the quarter-wave plate made from barium
30 fluoride, which is approximately half as thick. There is thus no reason stated here to make use of plates of higher order, although they are of course also possible.

35 [0024] This permissible thickness tolerance now yields the possibility of processing the end faces of the retardation plate as functional faces with refractive or diffractive action. The exit face is preferably

suitable for this purpose, since the direction of the propagation of light should be largely in the axial direction inside the retardation plate.

5 [0025] Up to a sine of the aperture angle (numerical aperture) of 0.2, the loss in the linear polarization degree is below 2% for a 157 nm half-wave plate made from calcium fluoride, and it still remains below 0.1% up to an NA of 0.15.

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[0026] A half-wave plate of zeroth order made from magnesium fluoride certainly permits a numerical aperture of up to 0.4 of equal quality. However, for plates of higher order the angular acceptance reduces rapidly and is only NA 0.1 for a half-wave plate of
15 twentieth order.

[0027] By contrast with magnesium fluoride, the inventive materials of the retardation plates thus
20 really do offer a larger angular acceptance. In the case of these angles, because of the birefringence properties that deviate for other main axes and is disadvantageous specifically in the case of lenses, the birefringence varying in the majority over the azimuth
25 angle also still plays no role.

[0028] In conventional optical designs, specifically in illumination systems and projection objectives in microlithography, it is not plane plates of centimeter
30 thickness that are provided for retardation plates, but individual plates of millimeter thickness, or they are provided as a negligibly thin layer on beam splitter prisms and the like. In all areas of these designs, however, where the beam angles lie in the abovenamed
35 region, the plane plates of centimeter thickness can, however, easily be incorporated into the design with corrections that are easily possible for the person skilled in the art. He is aided in this task by the

fact, as mentioned above, that the end faces are even to a certain extent accessible as functional and correction means.

5 [0029] The applicant's EP 1 102 100 A exhibits a microlithographic catadioptric projection objective having a polarization beam splitter cube at which the beam path is largely collimated. A quarter-wave plate is required between this and the concave mirror. As
10 thick plate according to the invention, it can be separated and removed from the thick, virtually planoconvex, lens in front of the concave mirror, also simultaneously with a removal for the 157 nm wavelength.

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[0030] The documents cited are also intended to be part of this application in full. The invention is particularly advantageous at 157 nm and in the neighborhood thereof, since the intrinsic birefringence
20 is particularly high here, but its application is also appropriate for the 193 nm microlithography systems and other optical systems, for example inspection systems.

Patent Claims

1. A retardation plate, in particular in a microlithography projection exposure machine, wherein
5 the retardation element consists of calcium fluoride crystal or barium fluoride crystal, and the optical axis of the retardation plate points approximately in the direction of the $\langle 110 \rangle$ crystal axis or a main crystal axis equivalent thereto.
- 10 2. The retardation plate as claimed in claim 1, wherein the retardation plate is a $\lambda/2$ plate, or a $\lambda/4$ plate, in particular of zeroth order.
- 15 3. The retardation plate as claimed in one of claims 1 or 2, wherein the retardation element has a diameter in the range from 50 to 300 mm.
- 20 4. The retardation plate as claimed in one of claims 1 to 3, wherein the retardation plate has a thickness variation of up to 2% or 1 mm.
- 25 5. The retardation plate as claimed in one of claims 1 to 4, wherein an end face is provided with a refractively or diffractively active structure or shape.
- 30 6. The retardation plate as claimed in one of claims 1 to 5, wherein it is mounted in an unstressed fashion.
- 35 7. A catadioptric projection objective, in particular in a microlithography projection exposure machine, having a retardation plate as claimed in one of claims 1-6.
8. A microlithography projection exposure machine, comprising an illumination system and a projection objective that images a pattern-bearing mask onto a
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photosensitive substrate, wherein it has a retardation plate as claimed in one of claims 1 to 6.

5 9. The microlithography projection exposure machine as claimed in claim 8, wherein the illumination system has a retardation plate as claimed in one of claims 1 to 6.

10 10. A method for producing semiconductor components with the aid of a microlithography projection exposure machine as claimed in claim 7 or 8.

Abstract:

Retardation plate made from cubic crystal

Centimeter thick plates made from calcium fluoride or barium fluoride with beam propagation in the direction of the $\langle 110 \rangle$ crystal direction or of a main axis equivalent thereto are provided as retardation plates for the deep ultraviolet; they can be installed in an unstressed fashion. Particularly suitable for microlithography at 157 nm.